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Abstract. In this contribution we describe planktonic assemblages, comprising their taxonomic composition and palaeoecological attributes, from the La Colonia Formation, Patagonia, Argentina. The palynological samples are from the section exposed at Estancia San Miguel, in the Telsen area, Chubut province. Diverse organic-walled remains of Chlorophyta and Charophyta taxa are documented. These include coenobia of two species of *Pseudopediastrum*, colonies of *Botryococcus* and zygospores of the form-genus *Ovoidites* (resembling extant genera of Zygnemataceae). The green algae together with dinoflagellate cysts (analyzed in a previous detailed study) indicate brackish to freshwater and freshwater depositional conditions for the middle and upper part of the Estancia San Miguel section, respectively. These water bodies developed along a coastal plain in the northern Patagonia probably during the Paleocene, in a phase of the extensive first transgressive event of the South Atlantic. The earliest record of *Pseudopediastrum brevicorne* for Patagonia is presented.

Key words. Organic-walled algae. Palaeoecology. Fresh/brackish water. Maastrichtian–?Paleocene. Patagonia.

Resumen. ANTIGUOS AMBIENTES COSTEROS EN UNA LÍNEA DE COSTA ATLÁNTICA DEL MAASTRICHTIANO–?PALEOCENO: UN ENFOQUE DESDE EL FITOPLANCTON. En esta contribución se presentan asociaciones planctónicas, incluyendo sus aspectos taxonómicos y atributos paleoecológicos, de la Formación La Colonia, Patagonia, Argentina. Las muestras palinológicas estudiadas provienen de la sección expuesta en Estancia San Miguel, área de Telsen, provincia de Chubut. Se documentan diversos elementos de pared orgánica de taxones de Chlorophyta y Charophyta. Estos incluyen cenobios de dos especies de *Pseudopediastrum*, colonias de *Botryococcus* y cigósporas del morfogénero *Ovoidites* (similares a cigósporas de géneros actuales de Zygnemataceae). Las algas verdes junto a los quistes de dinoflagelados (presentados en un detallado estudio previo) indican condiciones depositacionales de agua salobre a dulce para la parte media y de agua dulce para la parte superior de la sección Estancia San Miguel. Estos cuerpos de agua se desarrollaron a lo largo de una planicie costera en el norte de Patagonia, posiblemente durante el Paleoceno, en una fase del extenso primer evento transgresivo del Atlántico Sud. Se presenta el registro más temprano de *Pseudopediastrum brevicorne* para Patagonia.

Palabras clave. Algas de pared orgánica. Paleoecología. Agua dulce/salobre. Maastrichtiano–?Paleoceno. Patagonia.

DURING the Late Cretaceous–early Paleocene, the southern region of South America was characterized by relatively calm tectonic conditions and subjected to an overall transgressive phase of deposition (Uliana and Biddle, 1988). Wide areas of the extra Andean Patagonia were covered by the sea during the first Atlantic transgression recognized in the region (Gasparini *et al.*, 2015). The maximum extension of the coastline toward the continent occurred during the Maastrichtian, extending the marine influence up to the foot of the Andes (Malumián and Nañez, 2011). This transgression allowed developing an epicontinental sea that gave rise to various marginal marine and shallow marine shelf environments, because it did not achieve great depth (Nañez and Malumián, 2008). As a consequence, a series

of Late Cretaceous coastal plain sedimentary deposits accumulated, which represent estuaries, deltas, and lagoon/barrier complexes (Spalletti, 1996; Franzese *et al.*, 2003; Scasso *et al.*, 2012). In the area of the Somuncurá Plateau, northern Patagonia, these deposits correspond to the Allen, Coli Toro, Los Alamitos, Paso del Sapo, Lefipán and La Colonia formations (Page *et al.*, 1999).

In particular, the La Colonia Formation is widely exposed along the southeastern margin of the Somuncurá Plateau in Chubut Province, and has been extensively studied from stratigraphic, sedimentological and palaeontological approaches. Continental and marine fossils are indicative of the coastal nature of the depositional environments for the La Colonia Formation (Gasparini *et al.*, 2015 and references therein). Low diversity foraminifera assemblages from the Maastrichtian beds at Bajada Moreno (Northern Patagonia), included within the La Colonia Formation, also reflect marginal shallow marine settings (Nañez and Malumián, 2008).

Studies of the megaflora and palynological records from the La Colonia Formation have been previously published by Archangelsky *et al.* (1999), Archangelsky and Zamaloa (2003), Gandolfo and Cúneo (2005), Cúneo *et al.* (2013, 2014) and Gandolfo *et al.* (2014). Recently, the palynological composition of the La Colonia Formation exposed at the Estancia San Miguel section, in the area of Telsen, Chubut, was analyzed with emphasis on the description of neritic marine and fresh- to brackish water dinoflagellate cysts (Guler *et al.*, 2014). In that work we also showed the high frequencies reached by the green microalgae, and their palaeoecological significance for the environmental interpretation of these deposits. Notably, records of the freshwater to brackish microalgae are not abundant for the Late Cretaceous–Paleocene of Patagonia, even though widespread favorable habitats are identified by the lithofacies associations. The occurrence of species of *Pediastrum*, *Botryococcus* and of Zygnemataceae spores have been recognized in two plant bearing sections of the La Colonia Formation at the Cerro Bosta and Cañadón del Irupé/Quebrada del Helecho localities (Cúneo *et al.*, 2014). From the nearby Paleocene (Danian)-aged Bororó Formation, Scafati *et al.* (2009) recorded *Botryococcus*, *Coelastrum* and also Zygnemataceae spores in lacustrine beds. Likewise, Prámparo *et al.* (2006, 2008) interpreted lacustrine environment in a Late Cretaceous sauropod track site at Agua del Choique (southern Mendoza province, western Argentina) in the upper part of the Loncoche Formation, mainly based on the microalgae content. In that locality, the palynological associations are dominated by species of *Pediastrum* accompanied by representatives of *Botryococcus*, peridinioid dinoflagellate cysts and a few specimens of *Ovoidite*s and *Tetraporina*.

The main objective of this contribution is to document the organic-walled green algae and other aquatic palynomorphs that integrate the planktonic assemblages from the La Colonia Formation exposed at the Estancia San Miguel section together with dinoflagellate cysts previously described in Guler *et al.* (2014). Although this contribution is not intended to be an exhaustive taxonomic analysis, diagnostic characteristics of the studied planktonic remains are considered. We also summarize the ecological interpretation of these brackish to freshwater Maastrichtian–?Paleocene microalgae and other palynobiota assemblages. They constitute a significant tool for making palaeoenvironmental interpretations in the ancient marine marginal setting of the Patagonian region.

GEOLOGICAL AND SEDIMENTOLOGICAL SETTING

The palynological samples analyzed herein were obtained from exposures of the La Colonia Formation in the Telsen area, northeast of the Somuncurá-Cañadón Asfalto Basin, Chubut Province (Fig. 1). In this area, volcanic rocks of the Marifil Formation (182 My–185 My, Navarro *et al.*, 2015) constitute the basement. The La Colonia Formation overlies in sharp contact the fluvial deposits of the Albian Chubut Group (109 My, Navarro *et al.*, 2015), which are the oldest sedimentary rocks in Telsen. The thickness of the La Colonia Formation does not exceed 25 m in the Telsen area, but is thicker (up to approximately 205 m thick) in the center and west of the Somuncurá-Cañadón Asfalto Basin (Navarro, 2012). This is a result of a regional unconformity revealed by a progressive wedging from the south to the north, up to disappearance of these strata in the area of Cañadón Williams (Fig. 1) (Navarro *et al.*, 2015). The La Colonia beds are overlain by the Oligocene volcanics of the Somun Curá Formation (26 My, Ardolino and Franchi, 1996).

The sedimentology of the La Colonia Formation in the

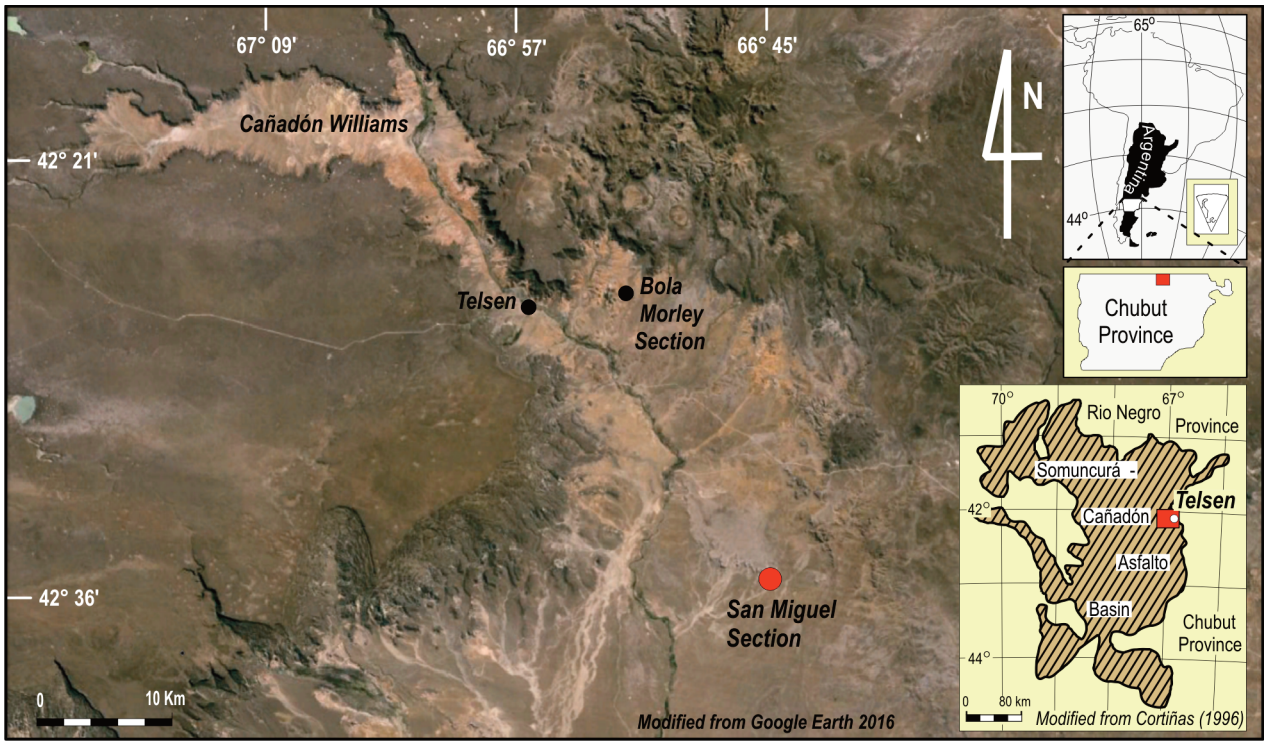


Figure 1. Location map of the Telsen area, Chubut Province, Argentina.

Telsen area is based on data collected from three sites (Fig. 1). The lower part of the unit was described in the vicinity of Telsen and the Bola Morley Hills (Navarro, 2012), where a basal lag of veneer conglomerate overlies a ravinement erosion surface. The latter, represents a key surface in a sequence stratigraphic context, given alternatively by wave or tidal energy, rapidly retreating coast lines and locates at the base of transgressive or high-stand systems tracts (*cf.* Posamentier and Allen, 1999; Chaumillon *et al.*, 2010). Above the basal conglomerate, four facies associations were recognized: a) shoreface to off-shore transition, b) tidal flats, c) lagoons with tidal influence, and d) ponds and shallow lakes without marine influence (Navarro, 2012; Navarro *et al.*, 2012). The two first facies associations were also recognized in the vicinity of Telsen and the Bola Morley Hills (Fig. 1). The 14.5 meter-thick Estancia San Miguel section, where intertidal and lacustrine facies with and without marine connection are represented, is shown in Figure 2. Facies associations recognized throughout the San Miguel section show two well-defined intervals characterizing a lower storm-dominated shoreface to offshore transition, and an upper tidal flat to lacustrine zone reflecting an overall coastline progradation during a high-stand stage. The lower section is predominantly composed of fine-grained thin- medium-bedded laminated sandstones with convolute structures overlying a strongly bioturbated siltstone interval. Hummocky and swaley cross-stratification within the laminated sandstones, indicate high-energy wave-induced bed forms related to storm episodes (Navarro *et al.,* 2012). The upper intertidal-flat facies association contains thoroughly developed heterolithic facies (flaser, lenticular and wavy lamination) associated within subtle coarsening upward cycles. Mudstones within this association show pervasive bioturbation; however, little bioturbated intervals show muddy rhythmites and intraclastic mud-chip conglomerates representing upper intertidal flats with intermittent exposure (Navarro *et al.,* 2012). The uppermost part of the section, in apparent continuity, is represented by ~4 m of a massive bioturbated slightly muddy more greenish to yellowish section without sandy laminae.

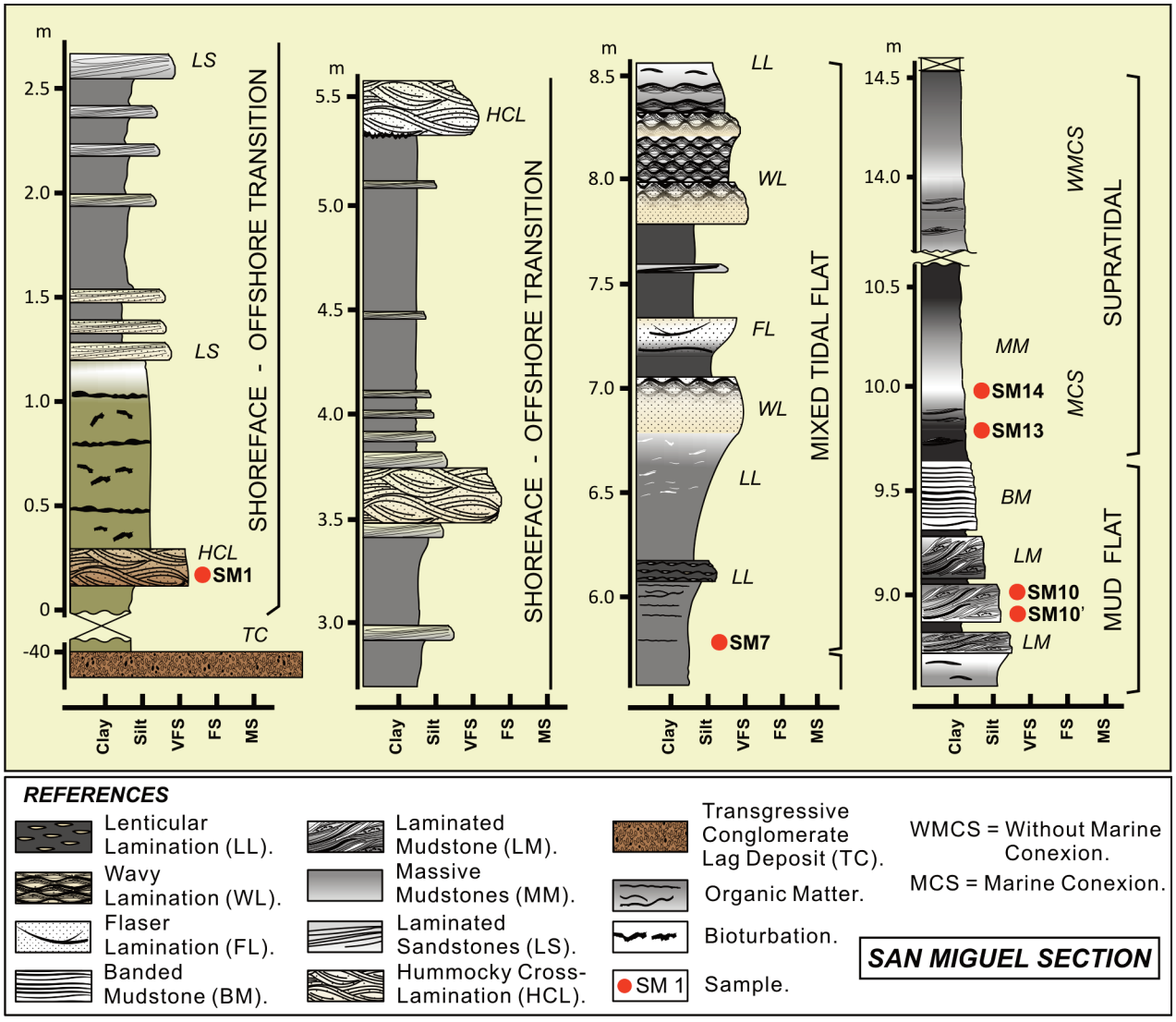


Figure 2. Stratigraphic section of the La Colonia Formation at the Estancia San Miguel locality, showing the distribution of facies and productive palynological samples.

AGE

The deposits at the Estancia San Miguel section represent the uppermost part of the La Colonia Formation in the Telsen Area (Navarro *et al.*, 2012). Based on micropalaeontological data, foraminifera and ostracods, a Campanian/Maastrichtian age was indicated for the upper marine deposits of the unit (Ardolino and Franchi, 1996 and references cited therein). A Maastrichtian age was established by Náñez and Malumián (2008) who studied the foraminiferal assemblages of the marine layers of the La Colonia Formation at the Bajada Moreno section, 100 km south of Telsen. Palynological data together with a stratigraphical criterion suggested an age not older that Paleocene for the uppermost part of the unit in the Telsen area, even though the age of the marine part of the La Colonia Formation is probably Late Cretaceous–early Paleogene (Guler *et al.*, 2014).

MATERIAL AND METHODS

Samples were collected at a regular distance of 20–30 cm from the base to the top of the Estancia San Miguel section where the La Colonia Formation outcropped. Following

standard techniques, the palynological processing of the samples included HCl and HF for removal of carbonates and silicates, respectively. Organic residues were sieved at 10 and 20 µm, stained with Bismarck C and mounted in glycerine jelly. Light microscopy observation of the slides was at 600× and 1000× magnification using a Nikon Eclipse 600 (serial number 77255). For the quantitative analysis, more than 300 palynomorphs (including dinoflagellate cysts, algae, spores and pollen grains) were counted in the palynological-fertile levels, except for sample SM7 in which the palynomorph number was <300 after examining the entire organic residue. The frequencies were calculated over the sum of total palynomorphs.

The classification of the Chlorophyta and Charophyta used in the text follows that of Lewis and McCourt (2004). For the dinoflagellate cysts the classification of Fensome *et al.* (1993) is followed. Images were taken with a Nikon Coolpix 950 digital camera. The microscope coordinates reference follows the sample and slide number for each specimen illustrated. Slides containing the illustrated specimens are stored in the Colección Palinológica, Laboratorio de Palinología (INGEOSUR-UNS), Bahía Blanca, Argentina.

RESULTS

Planktonic algae and invertebrates

Planktonic green microalgae were present in the six palynologically productive samples of the Estancia San Miguel section. The components recognized in the samples contain both reproductive (resting spores) and vegetative stages (coenobia and colonies) belonging to the Chlorophyta and Charophyta algae. The most representative green microalgae, in terms of relative frequencies from the La Colonia Formation in the San Miguel section, were analysed and illustrated in this work. All algal palynomorphs recognised in the samples were placed in each one of the outlined categories in Figure 3. Dinoflagellate cysts (Dinoflagellata) are also an important component of the assemblages and

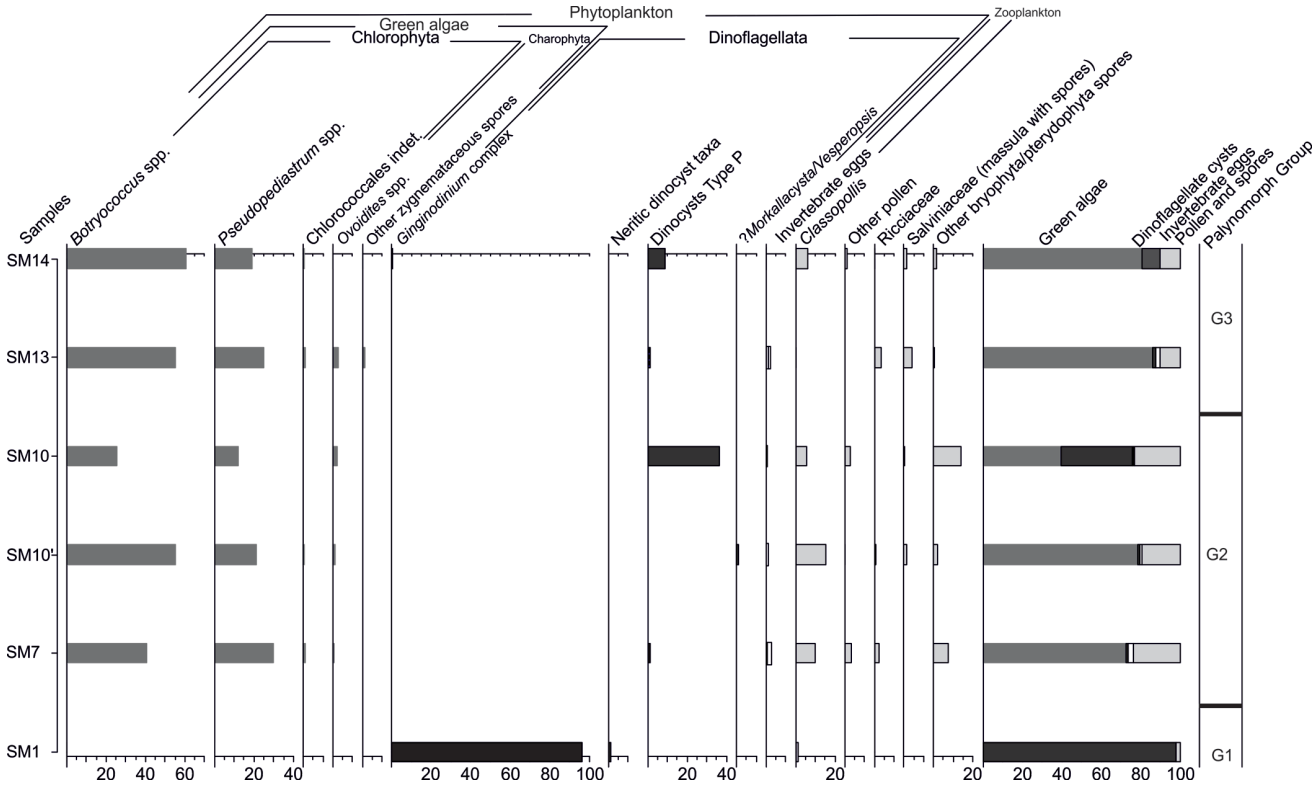


Figure 3. Percentage diagram of algal micro-remains including all palynological components of the samples (modified from Guler *et al.*, 2014) from the La Colonia Formation at San Miguel section.

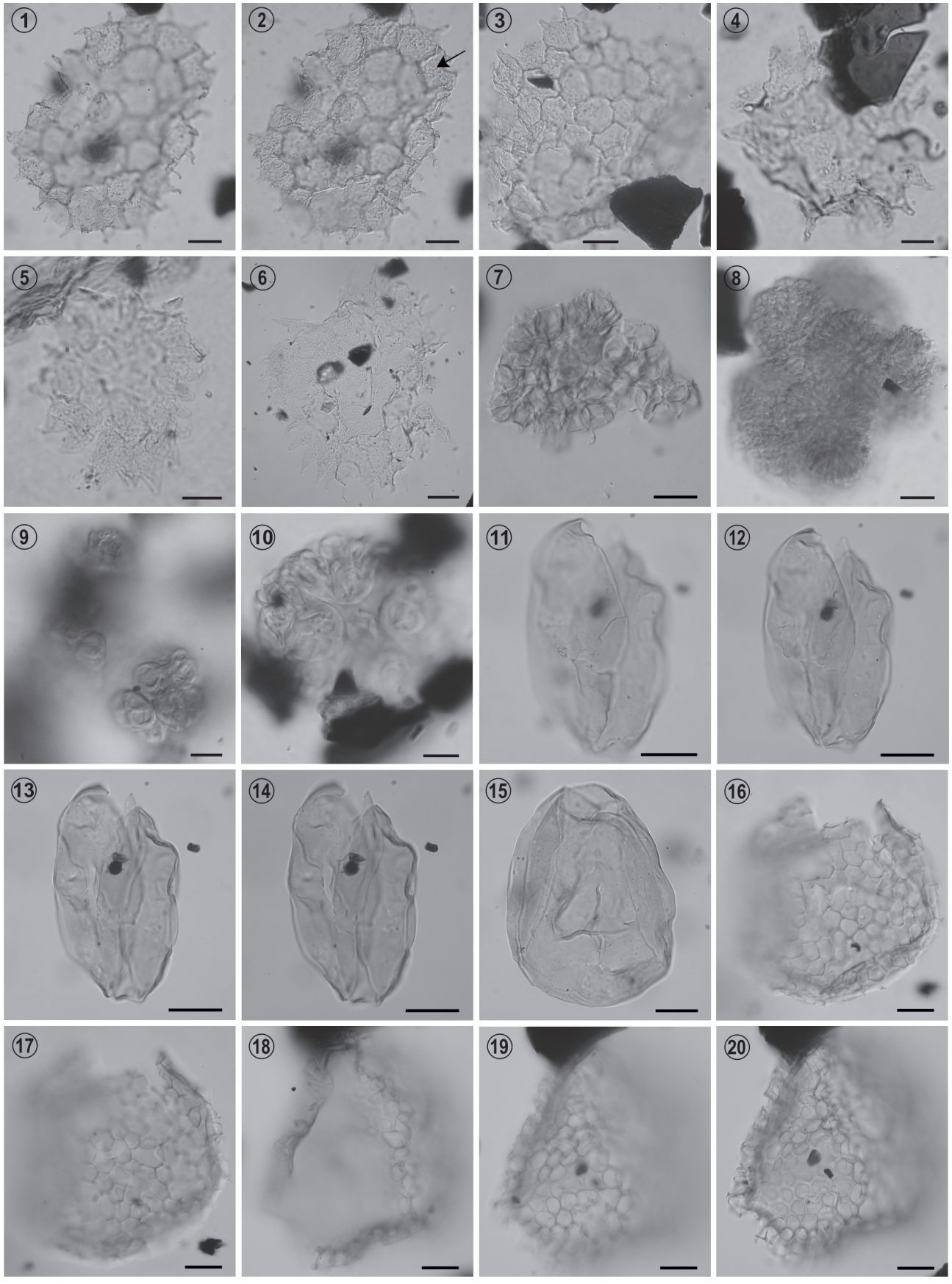
a complete taxonomic discussion of the species is included in Guler *et al.* (2014). Other aquatic palynomorphs identified represent zooplanktonic invertebrate eggs (see List of identified planktonic taxa).

Chlorophyceae. The freshwater Hydrodictyaceae family is well represented in the La Colonia Formation microalgae by different coenobia of the *Pediastrum* group. Recent molecular phylogenetic studies within the Hydrodictyaceae demonstrated that morphologically similar taxa have genetic diversity, and the genus *Pediastrum* Meyen 1829 was split into six genera: *Stauridinium* (Printz) Hegewald 2005, *Monactinus* (Turpin) Hegewald 2005, *Pediastrum, Parapediastrum* Hegewald 2005, *Pseudopediastrum* Hegewald 2005 and *Lacunastrum* McManus 2011 (Buchheim *et al*, 2005; McManus and Lewis, 2005, 2011; McManus *et al*., 2011). According to the present state of knowledge, some coenobia herein recovered can be referred to the extant *Pseudopediastrum brevicorne* (Braun) Jena and Bock 2014, and *Pseudopediastrum boryanum* var. *boryanum* (Turpin) Hegewald 2005 is also identified (Fig. 4.1–5). Other atypical or poorly preserved coenobia cannot be classified without doubt (Fig. 4–6). All morphotypes observed in the samples share morphological similarities, such as granulate cell wall and lack of intercellular spaces. Well-preserved specimens of *Pseudopediastrum brevicorne* exhibit a reticulate wall with conspicuous granules at the junctions of the muri (Fig. 4.2).

In Argentina, living *Pseudopediastrum brevicorne* it is restricted to low latitudes (between *ca.* 28 and 39° S) and its fossil presence at higher latitudes is remarkable (Zamaloa and Tell, 2005). *Pseudopediastrum brevicorne* (as *Pediastrum boryanum* var. *brevicorne*) appeared at higher southern latitudes of Patagonia in the Miocene Pinturas Formation and Cullen Formation (*ca.* 46 and 52° S respectively) and was interpreted as an indicator of mild climate (Zamaloa and Tell, 2005). The occurrence of this species in the phytoplankton of the La Colonia beds is the first published record of this species in the Cretaceous–Paleocene of Argentina and its earliest record. In the Cretaceous–Paleocene record of Argentina only *Pseudopediastrum boryanum* var. *boryanum* (as *Pediastrum boryanum* var. *boryanum*) has been previously recorded (Zamaloa and Tell, 2005). The specimens reported as *Pediastrum* spp. by Cúneo *et al.* (2014) from the La Colonia Formation at Cerro Bosta and Cañadón del Irupé/Quebrada del Helecho sites, could be also allocated (from the illustrations) as *Pseudopediastrum boryanum* var. *boryanum.* Currently *Pseudopediastrum boryanum* var. *boryanum* is widely distributed in Argentina (Tell, 2004) and occurs in a more or less wide range of mesotrophic to eutrophic waters (Komárek and Jankowská, 2001).

Trebouxiophyceae. Remains of colonies of the green fresh- to brackish-water alga *Botryococcus* Kützing 1849 are important components of the palynomorph assemblages of the San Miguel section (Fig. 3). These remains are variable in the shape, size and pattern of radially arranged cups distinguishing different morphological types (Fig. 4.7–10). In living colonies of *Botryococcus*, the individual cells are embedded in an extracellular matrix of polymerized, liquid hydrocarbons that allow colonies to float, presumably to increase exposure to light for photosynthesis at the surfaces of ponds or lakes. Only a few of the required morphologic features evaluated by Komárek and Marvan (1992) to discriminate species of living *Botryococcus* are consistently preserved and available in the fossil material. Additionally, the intraspecific taxonomy is remarkably less well known than in the *Pediastrum*-group, and there are several species

Figure 4. Green algae and invertebrate eggs recovered from the La Colonia Formation at the middle and upper part of the San Miguel section. **1–3, *Pseudopediastrum brevicorne*** (Braun) Jena and Bock, **1–2,** SM10' A 47.5/115.2, **1,** high focus; **2,** intermediate focus, showing a reticulate sculpture; **3,** SM10' A 42/104.5, general view. **4–5, *Pseudopediastrum boryanum* var. *boryanum*** (Turpin) Hegewald, **4,** SM10' A 58/112.6; **5,** SM10' A 57.2/122.5. **6, *Pseudopediastrum* sp.** SM14/08 B 30.5/96. **7–10, *Botryococcus* spp., 7**, SM13/08 D 31.3/119.7, colony with thin walled cups; **8,** SM10' A 55.5/112, large colony composed of agglomerated subcolonies; **9–10,** circular colonies with thick walled cups arranged in groups of four, **9,** colony composed of small group of connected cells, SM14/08 B 34/106, **10,** SM14/08 B 38.7/115.5. **11–14, *Ovoidites parvus*** (Cookson and Detmann) Nakoman, SM13/08 A 40.1/111; high to low focus; **15, *Ovoidites grandis*** (Pocock) Zippi, SM13/08 B 51.6/96.5. **16–20, *Hexarthra mira*** Hudson, **16–17,** SM13/08 D 35.5/119.4; complete specimen, **16,** high focus, **17,** intermediate focus; **18–20,** SM13/08 B 33.4/104.4, a single half; **18,** high focus; **19,** intermediate focus, **20,** low focus. **1–3, 8, 11–20:** scale bar= 20 µm; **4–7, 9–10:** scale bar= 10 µm.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of uncertain taxonomy (Jankowská and Komárek, 2000; Senousy *et al.*, 2004). Given these limitations, in our study the different form-types of *Botryococcus* are not assigned to species. Significantly, the colony form-types reported herein can be compared with the discriminated form-species using SEM analysis *(Botryococcus* sp. 1 to *Botryococcus* sp. 4) from the Danian Bororó Formation, approximately 100 km south from the deposits studied herein (Scafati *et al.*, 2009, fig. 5, A–D).

Botryococcus generally lives in freshwater, but considerable abundances in brackish habitats are also known (Batten and Grenfell, 1996). Zippi (1998) refers that it commonly forms water-blooms in alkaline lakes and ponds. At present *Botryococcus* is broadly distributed in tropical to temperate areas (Batten and Grenfell, 1996) and usually abundant in shallow-water pools in case of little precipitation (Guy-Ohlson, 1992). These algae have an oligotrophic to mesotrophic character (Komárek and Marvan, 1992; Chmura *et al.*, 2006), however also are reported from eutrophic environments.

Zygnemataceae. Different types of spores of zygnematacean algae are present in small frequencies (up to 5% in sample SM13) in the palynological spectra from La Colonia beds. Most of our specimens are ellipsoidal in equatorial view, with psilate to scabrate wall and composed of two halves with a longitudinal dehiscence (Fig. 4.11–15). The form-genus *Ovoidites* (Potonié) Krutzsch 1959 represents morphotypes identical to zygospores of several species of the extant *Spirogyra* Link 1820 and the related genus *Sirogonium* Kützing 1843 (Van Geel and Grenfell, 1996; Zippi, 1998).

These filamentous green algae are presently widespread in freshwater habitats as slow-moving water, or shallow stagnant ponds (Randhawa, 1959). Generally occurring as free-floating masses, but few members are found attached to substrate in the littoral zone of lakes and in flowing water (Lee, 2008). Species of *Spirogyra* are important primary producers in many aquatic food webs, especially in habitats with neutral or slightly acidic pH values, and the zygospores formation occurs during or toward the end of spring or summer (Gerrath, 2003; Stancheva *et al.*, 2013).

Peridiniaceae. Throughout the San Miguel section, rounded-pentagonal peridinioid-shaped, non-pigmented (phototrophic) peridiniacean cysts reach high percentage values (Fig. 3). An almost monotypic assemblage of small, spiny, thin-walled palaeoperidinioid dinoflagellate cysts grouped in ?*Ginginodinium* sp. with significant morphological variability characterizes the base of the section. Although many specimens were observed, in a very few ones it was possible to identify the typical palaeoperidinioid archeopyle; it involves three intercalary and the three dorsal precingular plates (Guler *et al.*, 2014: fig. 4.2). Palaeoperidinioid dinoflagellate cysts have been recorded in marine strata since the Cretaceous, however, occurrences in non-marine environments could have occurred since the Cenozoic (Fensome *et al.*, 1993).

Dinocysts type P from the middle and upper part of the section, include small translucent extremely thin-walled peridiniacean cysts with a weakly granulate surface and incipient development of one apical and two symmetrical short antapical horns. Most of the specimens occur poorly preserved, most of them folded and, in the few cases where the archeopyle was observed, it was not possible to determine the number or the plate series involved. Apparently, the archeopyle is formed by the loss of precingular, intercalary and/or apical plates, but it could not be accurately defined. Dinocysts type P resemble specimens of *Saeptodinium* Harris 1974 from Australian non-marine Paleocene deposits (Harris, 1974), and *Holmwoodinium* sp. cf. *H. notatum* Batten 1985 which appear in low-salinity to freshwater assemblages in the Lower Cretaceous of Great Britain (Batten, 1985). Dinocysts type P may be compared also with the cysts of *Peridinium* Ehrenberg 1832 from sedimentary sequences in southeastern Buenos Aires Province, related to the Holocene transgression (Borel *et al.,* 2003; Borel, 2007).

Scarce specimens of ?*Morkallacysta* Harris 1974 were recorded in the upper part of the section exhibiting clear palaeoperidinioid archeopyle (1I3P) (Guler *et al.*, 2014: figs. 5.5 and 5.7–9). These non-marine dinoflagellate cysts were originally described for the Paleocene of Australia with a triangular archeopyle (Harris, 1974). A taxonomic revision is necessary to consider the classification of this taxon.

More diversity in La Colonia water bodies: zooplanktonic eggs. Other organic-walled microfossils with complex walls conformed by numerous cell-like elements and with a longitudinal dehiscence suture (Fig. 4.16–20) complete in low

proportions (<2 %) the assemblages. These conspicuous palynomorphs are attributed to the form-genus *Schizosporis reticulatus* Cookson and Dettmann 1959. Its dehiscence suture has been commonly interpreted as a diagnostic feature of the Zygnemataceae zygospores (Grenfell, 1995). However, aquatic invertebrates such as rotifer of the Monogononta Class produce diapause eggs with a similar slit suture. Moreover, zygospores do not have walls with cell-like units whereas this is a characteristic of the rotifer eggs of the several genera. In particular, *Hexarthra mira* Hudson, 1871 produce eggs that equate to the microfossils of the form taxon *Schizosporis reticulatus* (Van Geel, 1998).

Resting eggs of invertebrates (including rotifers) have been mentioned and illustrated in Holocene palynological studies of fresh to brackish environments in several sites (Van Geel, 2001; Head *et al.*, 2003; Borel, 2007). These eggs can survive in the sediments until favorable conditions re-occur and constitute a survival strategy in ephemeral water bodies subjected to seasonal dry periods. In particular, rotifers constitute a diverse and abundant zooplanktonic group in shallow lakes, although some of them also have an important role developing in the periphyton at the vegetated littoral zones. *Hexarthra mira* and other species of this genus are known from the Neotropical region of South America (Turner, 1987) and they are warmth-demanding planktonic organisms (Van Geel, 1998).

Palaeoenvironmental interpretation. Three major groups of palynological assemblages were identified based on both species composition and relative frequencies for the San Miguel section (Guler *et al.*, 2014). Productive palynological samples show a gradient from phytoplankton assemblages dominated by brackish water dinoflagellate cysts to fully freshwater planktonic assemblages at the uppermost part of the deposits (Fig. 3).

Pseudopediastrum spp., *Botryococcus* spp. and *Ovoidites* spp. were the dominant components of the palynomorph Groups 2 and 3 (Fig. 3), in the middle and uppermost part of San Miguel section respectively. The abundance of these non-marine algae, together with Dinocysts type P and scarce specimens of the non-marine ?*Morkallacysta* spp. (Fig. 3, Group 2), reveal the existence of low-salinity or low-salinity to freshwater bodies associated to mixed and mudflat environments (see Fig. 2). The green algae are well preserved suggesting they were deposited *in situ* or after minimal transport, representing environments with low energy fluxes. The nearby presence of marshy vegetated areas is shown by the important values of pollen of *Classopollis* Pflug 1953. Water ferns are represented by spores of aquatic bryophytes (Ricciaceae), whereas pterydophyte spores and pollen grains related to Proteaceae, Arecaceae, Liliaceae, Gunneraceae and Podocarpaceae are subordinated (Guler *et al.*, 2014).

In the uppermost part, planktonic assemblages are almost entirely composed by *Pseudopediastrum* spp. and *Botryococcus* spp., and by low proportions of zygnematacean spores, rotifer eggs and *?Vesperopsis* sp. (Fig. 3, Group 3). In agreement, an increase in the frequencies of freshwater aquatic pteridophytes (massulae with microspores of Salviniaceae) is observed. This assemblage is associated with massive mudstones (Fig. 2) and reflects freshwater bodies linked to a supratidal environment, without tidal influence.

Reduced salinity conditions and/or salinity-related changes to a shallow marine coastal environment were also suggested for the basal part of the San Miguel section (Guler *et al.*, 2014). The association is strongly dominated by an almost monotypic assemblage of palaeoperidinioid cysts, denoting salinity-related stressed water conditions, and freshwater green microalgae are practically absent.

The predominance of fine-grained textures –mainly mudstones– throughout the San Miguel section, but particularly true toward the top is associated to low-energy depositional processes, suggesting environments dominated by settling and flocculation from suspension. This may imply brackish water conditions related to coastal environments relatively isolated or disconnected from the direct open-marine influence. Furthermore, the changes in the palynomorph content is consistent with the facies associations interpretation throughout the La Colonia Formation in the Telsen area, from which shallowing-upward trend indicates a progressive shifting of the shoreline basinward, related to highstand progradation of an estuarine-like mosaic with complex brackish to freshwater intertidal lagoons and ponds (Navarro, 2012; Navarro *et al.*, 2012).

DISCUSSION AND CONCLUSIONS

By the Late Cretaceous–Paleocene, freshwater dinoflagellates and green algae dominates the planktonic assemblages of the inland water bodies worldwide. Continental phytoplankton only just diversified during the Eocene, with the development of freshwater diatoms and chrysophytes (Martin Closas, 2003). This highlights the relevance of these organic-walled green algae and dinoflagellate cyst analysis from Maastrichtian–Paleocene coastal environments.

Several palynological studies carried out in Mid to Late Holocene estuarine deposits of Pampean coast revealed the potential of green algae and dinoflagellate cysts as palaeobioindicators (Borel, 2007; Vilanova *et al.*, 2006; Mourelle *et al.*, 2015). These palynological spectra indicate the occurrence of coastal water bodies showing its physical-chemical variability caused by sea-level changes during the Holocene transgressive-regressive event in the studied coastal sites of Pampa grasslands. Comparison to other proxies (diatoms, pollen and gastropods) enhanced the value of the green algae and non-marine dinoflagellate cysts in the palaeoenvironmental reconstructions of those Holocene sequences. Palynological similarities between these modern-Holocene coastal systems and the ancient coastal setting of the La Colonia Formation were noticed and properly applied in this study. It seems a fundamental tool to unravel the environmental trend through the Maastrichtian–?Paleocene marginal deposit of Patagonia.

In summary, the palynological content of the fine-grained deposits of La Colonia Formation at the San Miguel section in the Telsen area reveals productive and shallow ancient coastal ecosystems with variable salinity conditions. The variation in the composition and proportions of the non-marine aquatic palynomorphs, mainly green microalgae and dinoflagellate cysts, allowed characterizing the different low-salinity water bodies developed in an intertidal flat setting. Changes in the palynological algal composition, along with sedimentological analysis, leads to the characterization of the depositional setting and palaeoenvironmental shifts in the San Miguel section of the La Colonia Formation.

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LIST OF IDENTIFIED PLANKTONIC TAXA

Green algae

Division CHLOROPHYTA (Pascher) *emend.* Lewis and McCourt 2004
Class CHLOROPHYCEAE (Kützing) Christensen 1994
Order SPHAEROPLEALES Deason *et al.* 1991
Family HYDRODICTYACEAE Dumortier 1829 *emend.* Deason *et al.* 1991
Genus *Pseudopediastrum* Hegewald 2005 (in Buchheim *et al.* 2005)
Pseudopediastrum brevicorne (Braun) Jena and Bock 2014
Pseudopediastrum boryanum var. *boryanum* (Turpin) Hegewald 2005
Pseudopediastrum sp.
Class TREBOUXIOPHYCEAE Friedl 1995
Order TREBOUXIALES Friedl 1995
Family BOTRYOCOCCACEAE Wille 1909
Genus *Botryococcus* Kützing 1849
Botryococcus spp.
Division CHAROPHYTA (Karol *et al.*) *emend.* Lewis and McCourt 2004
Class CONJUGATOPHYCEAE Engler 1892
Order ZYGNEMATALES Borge and Pascher 1913
Family ZYGNEMATACEAE (Meneghini) Kutzing 1843
Form-genus *Ovoidites* (Potonié) Krutzsch 1959
Ovoidites grandis (Pocock) Zippi 1998
Ovoidites parvus (Cookson and Detmann) Nakoman 1966
Division DINOFLAGELLATA (Bütschli) Fensome *et al.* 1993
Class DINOPHYCEAE Pascher 1914
Order PERIDINIALES Haeckel 1894
Suborder PERIDINIINEAE (Autonym)
Family PERIDINIACEAE Ehrenberg 1831
Subfamily PALAEOPERIDINIOIDEAE (Vozzhennikova) Bujak and Davies 1983
Genus *Ginginodinium* Cookson and Eisenack, *emend.* Lentin and Williams 1976
?*Ginginodinium* sp.
Subfamily INCERTA
Dinocyst type P
Subfamily INCERTA
Genus *Morkallacysta* Harris 1974
?*Morkallacysta* spp.
Suborder CERATIINEAE Fensome *et al.* 1993
Family CERATIACEAE Willey and Hickson 1909
Genus *Vesperopsis* Bint *emend.* Mao *et al.* 1999
?*Vesperopsis* sp.

Invertebrate zooplankton

Phylum ROTIFERA Cuvier, 1817
Class MONOGONONTA Plate, 1889
Order Flosculariacea Harring, 1913
Family Hexarthridae Bartos, 1959
Genus *Hexarthra* Schmarda, 1854
Hexarthra mira Hudson, 1871

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